



INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification ⁶ : B01J 19/00	A1	(11) International Publication Number: WO 99/16542 (43) International Publication Date: 8 April 1999 (08.04.99)
(21) International Application Number: PCT/US98/19567 (22) International Filing Date: 17 September 1998 (17.09.98) (30) Priority Data: 08/938,228 26 September 1997 (26.09.97) US (71) Applicant: BATTIELLE MEMORIAL INSTITUTE [US/US]; Pacific Northwest Division, Intellectual Property Services, P.O. Box 999, Richland, WA 99352 (US). (72) Inventors: MARTIN, Peter, M.; 7703 West 13th Avenue, Kennewick, WA 99337 (US). BENNETT, Wendy, D.; 907 West 26th Avenue, Kennewick, WA 99337 (US). MATSON, Dean, W.; 4104 West 17th Avenue, Kennewick, WA 99337 (US). STEWART, Donald, C.; 1922 Thayer, Richland, WA 99352 (US). DROST, M., Kevin; 3807 Meadow View Court, Pasco, WA 99301 (US). WEGENG, Robert, S.; 2603 Harris Avenue, Richland, WA 99352 (US). PEREZ, Joseph, M.; 2457 Montgomery Avenue, Richland, WA 99352 (US). FENG, Xiangdong; 3720 Lexington, West Richland, WA 99353 (US). LIU, Jun; 5656 Collins Road, West Richland, WA 99353 (US).		(74) Agent: ZIMMERMAN, Paul, W.; Battelle Memorial Institute, Pacific Northwest Division, Intellectual Property Services, P.O. Box 999, Richland, WA 99352 (US). (81) Designated States: AU, CA, JP, MX, NZ, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE). Published <i>With international search report.</i> <i>Before the expiration of the time limit for amending the</i> <i>claims and to be republished in the event of the receipt of</i> <i>amendments.</i>
(54) Title: MICROCHANNEL LAMINATED MASS EXCHANGER AND METHOD OF MAKING <div data-bbox="328 1144 1289 1684" data-label="Image"> </div> (57) Abstract <p>The present invention is a microchannel mass exchanger (100) having a first plurality of inner thin sheets (106, 116, 200, 300) and a second plurality of outer thin sheets (110, 118, 204, 302, 504, 510). The inner thin sheets (106, 118, 200, 300) each have a solid margin (108) around a circumference, the solid margin (108) defining a slot (104, 508) through the inner thin sheet (106, 116, 200, 300) thickness. The outer thin sheets (110, 118, 204, 302, 504, 510) each have at least two header holes (112, 202) on opposite ends and when sandwiching an inner thin sheet (106, 116, 200, 300). The outer thin sheets (110, 118, 204, 302, 504, 510) further have a mass exchange medium (400, 500). The assembly forms a closed flow channel assembly wherein fluid enters through one of the header holes into the slot and exits through another of the header holes after contacting the mass exchange medium.</p>		

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece	ML	Mali	TR	Turkey
BG	Bulgaria	HU	Hungary	MN	Mongolia	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MR	Mauritania	UA	Ukraine
BR	Brazil	IL	Israel	MW	Malawi	UG	Uganda
BY	Belarus	IS	Iceland	MX	Mexico	US	United States of America
CA	Canada	IT	Italy	NE	Niger	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NL	Netherlands	VN	Viet Nam
CG	Congo	KE	Kenya	NO	Norway	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NZ	New Zealand	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	PL	Poland		
CM	Cameroon	KR	Republic of Korea	PT	Portugal		
CN	China	KZ	Kazakstan	RO	Romania		
CU	Cuba	LC	Saint Lucia	RU	Russian Federation		
CZ	Czech Republic	LI	Liechtenstein	SD	Sudan		
DE	Germany	LK	Sri Lanka	SE	Sweden		
DK	Denmark	LR	Liberia	SG	Singapore		
EE	Estonia						

**MICROCHANNEL LAMINATED MASS EXCHANGER
AND METHOD OF MAKING**

5

FIELD OF THE INVENTION

The present invention relates generally to a mass exchanger and method of making a mass exchanger. As used
10 herein, the term "mass exchanger" is defined as an apparatus wherein solute molecules in a solvent pass from the solvent to a mass transfer medium, or particles in a fluid pass from the fluid to a mass transfer medium.

15

BACKGROUND OF THE INVENTION

Mass transfer has been well known and studied for many years. Examples include chemical separations, catalytic reactions wherein a species contacts a catalyst
20 surface and exchanges mass with another species to form a compound, i.e. catalytic reaction. Exemplary apparatus include kidney dialysis machines for separations wherein the mass transfer medium is a tube through which certain compounds pass because of a concentration gradient from
25 the fluid within the tube to the fluid exterior to the tube. An example of a catalyzed mass transfer apparatus is a catalytic converter to reduce pollutants in automobile exhaust. Disadvantages of large scale mass transfer have been recognized and efforts made to use
30 small scale mass transfer.

Separations and catalyzed reactions have been shown in microscale apparatus as well. U.S. patent 5,534,328 to Ashmead et al. show a laminated structure wherein flow
35 channels are made by etching a laminate partially through its thickness and stacking another laminate upon it to form a flow channel. Header holes through the laminate thickness are provided for inlets and outlets. Ashmead et al. suggest incorporating catalytic activity by

- 2 -

packing a segment of a channel with catalytic beads or depositing catalytic materials onto the surface of a channel. Ashmead et al. further suggest mixer chambers formed by a half channel etched on the bottom of one
5 laminate in combination with a half channel on the top of another laminate. A disadvantage of the construction of Ashmead et al. is the complexity and expense of carving laminates partially through the thickness of the laminates. A further disadvantage of the construction of
10 Ashmead et al. is the small aspect ratio of width to depth of their channels for flow resistance and pressure drop. The construction of Ashmead et al. cannot achieve diffusive mass transfer, or controlled mixing by actuation.

15 Thus, there remains a need for a microchannel mass exchanger having a lower cost of fabrication and which provides a reduced pressure drop.

20 SUMMARY OF THE INVENTION

The present invention is a mass exchanger and method of making it. The method of making a microchannel mass exchanger, has the steps of:

- 25 (a) forming at least one inner thin sheet having a solid margin around a circumference, the solid margin defining a slot through a thickness;
- (b) forming at least one outer thin sheet having at least two header holes positioned within the
30 solid margin and positioned at opposite ends of a slot length, wherein the at least one inner thin sheet is placed adjacent the at least one outer thin sheet, the solid margin sealably spacing the at least one outer thin sheet the at least one outer thin sheets defining at
35 least one longitudinal wall of a flow channel having a

- 3 -

length parallel to a thin sheet length, wherein a fluid enters through one of the header holes into the slot to flow in a direction parallel or longitudinal to the length of the flow channel and exits through another of the header holes;

(c) placing a mass transfer medium on at least one of the outer thin sheet within the solid margin;

(d) stacking the at least one inner thin sheet in contact with the at least one outer thin sheets into a stack and placing an end block on the at least one inner thin sheet as a pre-bonded assembly; and

(e) bonding the pre-bonded assembly into the microchannel mass exchanger.

The apparatus of the present invention is microchannel mass exchanger, having:

(a) at least one inner thin sheet having a solid margin around a circumference, the solid margin defining a slot through a thickness;

(b) at least one outer thin sheet having at least two header holes positioned within the solid margin and positioned at opposite ends of a slot length, wherein the at least one inner thin sheet is placed adjacent the at least one outer thin sheet, the solid margin sealably spacing the at least one outer thin sheet the at least one outer thin sheets defining at least one longitudinal wall of a flow channel having a length parallel to a thin sheet length, wherein a fluid enters through one of the header holes into the slot to flow in a direction parallel or longitudinal to the length of the flow channel and exits through another of the header holes;

(c) a mass transfer medium on at least one of the at least one outer thin sheet within the solid margin;

- 4 -

- (d) the at least one inner thin sheet in contact with the at least one outer thin sheets into a stack with an end block on the at least one inner thin sheet as a pre-bonded assembly; and
- 5 (e) the pre-bonded assembly bonded into the microchannel mass exchanger.

An advantage of the present invention is that the slot may have a large aspect ratio of its width to its depth or thickness. Another advantage of the present invention is that it accommodates a variety of materials including materials not amenable to bulk or surface micromachining, for example ceramics. A further advantage is that the method may be used in high volume production which is a key to economical and commercially

10

15 viable products.

The subject matter of the present invention is particularly pointed out and distinctly claimed in the concluding portion of this specification. However, both the organization and method of operation, together with

20 further advantages and objects thereof, may best be understood by reference to the following description taken in connection with accompanying drawings wherein like reference characters refer to like elements.

25 BRIEF DESCRIPTION OF THE DRAWINGS

- FIG. 1a is an exploded view of a stack of thin sheets forming a one-pass serpentine path once through mass exchanger.
- 30 FIG. 1b is a side view of an inner thin sheet with no header holes.
- FIG. 1c is a side view of an outer thin sheet with two header holes.
- FIG. 1d is a side view of an end block with one
- 35 header hole.

- 5 -

FIG. 2a is an exploded view of a stack of thin sheets forming a two-pass serpentine path once through mass exchanger.

FIG. 2b is a side view of an inner thin sheet with two header holes.

FIG. 2c is a side view of an outer thin sheet with four header holes.

FIG. 2d is a side view of an end block with two header holes.

FIG. 3a is an exploded view of a dual fluid microchannel mass exchanger.

FIG. 3b is a side view of an inner thin sheet with two header holes on one side of the inner thin sheet.

FIG. 3c is a side view of an outer thin sheet with four header holes.

FIG. 3d is a side view of an end block with two header holes.

FIG. 3e is a side view of an inner thin sheet with two header holes on diagonal corners of the inner thin sheet.

FIG. 3f is a side view of a semi-circular inner thin sheet.

FIG. 3g is a side view of a semi-circular outer thin sheet.

FIG. 3h is a side view of a semi-circular end block.

FIG. 4 is an isometric view of an outer thin sheet with a mass transfer medium bonded thereto.

FIG. 5a is an isometric view of an outer thin sheet with a mass transfer medium integral thereto.

FIG. 5b is a magnified view of the mass transfer medium.

FIG. 5c is a side view of an inner thin sheet with a perforated mass transfer medium.

- 6 -

FIG. 5d is a side view of an inner thin sheet with an offset perforated mass transfer medium.

FIG. 5e is cross section of an assembly of perforated inner thin sheets with outer thin sheets
5 therebetween.

FIG. 6 is an exploded view of a microcomponent mass exchanger.

FIG. 7. is a graph of ammonia concentration versus absorption film thickness for Example 1.
10

DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

Referring to FIG's 1a and 2a, two embodiments of
15 the present invention of a once through mass exchanger 100 are shown. Common to both embodiments are (a) at least two thin sheets 102 stacked and bonded to form at least one flow channel 104. The plurality of thin sheets 102 has subcategories of (b) at least one inner thin
20 sheet 106, each having a solid margin 108 around a circumference, the solid margin 108 defining a slot 104 through a thickness; and (c) at least one outer thin sheet 110, each having at least two header holes 112 positioned within the solid margin 108 and positioned at
25 opposite ends of a slot length L1. Each of the inner thin sheets 106 may be sandwiched between a pair of the outer thin sheets 110 to form a closed flow channel assembly 114 wherein fluid enters through one of the header holes 112 into the slot 104 and exits through
30 another of the header holes 112.

When each of the inner thin sheets 106 is sandwiched between a pair of the outer thin sheets 110, the solid margin 108 sealably spaces the outer thin sheets 110 and the outer thin sheets 110 define
35 longitudinal walls of a flow channel 104 with a length

- 7 -

L-1 parallel to a thin sheet length L-2, wherein a fluid enters through one of the header holes 112 into the slot 104 to flow in a direction parallel or longitudinal to the length L-2 of the flow channel 104 and exits through another of the header holes 112. Aspect ratios of the width W of the slot 104 to the thickness range from about 10 to about 100.

The stacked plurality of thin sheets 102 define an outer surface defined by a plurality of edge thicknesses 115 of the stacked plurality of thin sheets 102. The outer surface may be proximate a thermal load (not shown) so that the thermal load (heat or cool) is transmitted via conduction through the stacked plurality of thin sheets 102 margin and also transmitted via convection between the stacked plurality of thin sheets 102 and the fluid in the flow channel 104.

Distinctions between the embodiments are shown in FIG's 1b, 1c, 1d, 2b, 2c, 2d. In FIG. 1b, the inner thin sheet 116 has the slot 104 defined by the solid margin 108 but no other features. In FIG. 2b, the inner thin sheet 200 has the slot 104 defined by the solid margin 108 and it has header holes 202. In FIG. 1c, the outer thin sheet 118 has two header holes 112 whereas in FIG. 2c, the outer thin sheet 204 has four header holes 112. In FIG. 1d, the end block 120 has one header hole 112 for an inlet on one end and an outlet on the opposite end, whereas in FIG. 2d, the end block 206 has two header holes 112 so that the inlet and outlet are on the same end. In operation, the embodiment of FIG's 1a, 1b, 1c and 1d has a single fluid that passes through sequential inner thin sheets 116 in a serpentine path. In the embodiment of FIG's 2a, 2b, 2c, and 2d, the single fluid passes through every other inner thin sheet 200 in a serpentine path then reverses and passes through the alternating inner thin sheets 200 in a reverse serpentine

- 8 -

path. In both embodiments, the single fluid passes through each inner thin sheet 106 once.

The flow channels 104 may be any length or width (e.g. 5 cm X 1 cm), but must have a thickness less than
5 about 0.015 cm to achieve the enhanced mass transfer coefficients characteristic of microchannels.

The material(s) of construction may be the same for each element or varied. In a preferred embodiment, the material(s) of construction is the same for each element
10 to facilitate bonding and sealing of the elements one to another. Materials include but are not limited to metals, for example stainless steel or copper, plastics, and ceramics.

A dual fluid embodiment is shown in FIG's 3a, 3b, 3c, 3d, 3e. Fins may be made, if desired for
15 facilitating heat transfer to or from the outer surface, by offsetting the alignment of slots 104 and header holes 112.

Further geometric arrangements are shown in FIG's 3f, 3g, 3h. FIG. 3f shows an inner thin sheet 300
20 that has a semi-circular side view. FIG. 3g shows an outer thin sheet 302 that has a semi-circular side view, and FIG. 3h shows an end block that has a semi-circular side view. A semi-circular design permits compact
25 construction around other system components, for example a pipe or electrical chase. Of course, other non-linear geometries may be used.

Bonding of metallic laminates may be by brazing, soldering, or diffusion bonding. Each laminate is
30 cleaned to remove any oxide coating that would interfere with bonding. A preferred method of cleaning is with an acid rinse. The pre-bonded assembly or stack is compressed in a jig and heated under vacuum. For copper, the temperature is about 630°C at a pressure of 6000 psi
35 for about 4 hours to achieve a reliable diffusion bond.

- 9 -

For aluminum, 350°C, 10,000 psi for 2 hours; and for stainless steel type 304, 600°C, 6000 psi for 2 hours.

The mass transfer medium may be a solid material, for example catalyst, absorbent material, adsorbent material, hydrophobic layer, hydrophilic layer, or combination thereof. The mass transfer medium may also be a porous or perforated material, wherein the term "porous material" refers to material through which diffusion occurs but bulk flow or "weeping" flow is prevented. When the pores or holes are of a size to permit bulk flow or weeping, the mass transfer medium is referred to herein as a perforated material. The porous or perforated material may also be a solid material or have a solid material thereon. A perforated material may be used for mixing two streams. An alternative form of mass transfer medium is a self assembling monolayer bonded to the surface of the outer thin sheet 118 within the margin 108, or bonded within the pores of a porous or perforated sheet wherein the self assembling monolayer further has one or more functional groups that would contact a fluid. The mass transfer medium may include active microcomponents, for example micro-propellers for imparting motion to a fluid.

For attachment of a self assembling monolayer, it may be necessary to coat a surface with an oxide material, for example silica, titania, or zirconia. Organic molecules useful as self assembling monolayers include silane, for example chlorosilane, alkoxysilane, and combinations thereof. Functional groups include but are not limited to mercaptan, mercaptan related compounds, amines, methyl, halogen, nitrile, pyradines, alkyls, polymers, and combinations thereof. For binding metals, tris(methoxy)mercaptopropylsilane (TMMPS) has a thiol group with a high affinity for binding metals. Alternatively, therefore, using TMMPS on both ends of the

- 10 -

organic molecule may permit attachment of the organic molecule directly to a metal outer thin sheet without a coating. By placing only hydroxyl functional groups on the organic molecule, water may be removed from a mixture to parts per trillion levels. For example a mixture of oil and water may have the water removed in this manner. This may be especially useful for removing tritiated water from oil. Inorganic materials may be attached via self assembling monolayers as described in W091/17286 published November 14, 1991, PROCESS FOR DEPOSITING THIN FILM LAYERS ONTO SURFACES MODIFIED WITH ORGANIC FUNCTIONAL GROUPS AND PRODUCTS FORMED THEREBY, hereby incorporated by reference. Briefly, a polymeric surface is sulfonated then exposed to a solution of metal ionic species so that the metal ionic species deposits on the sulfonated surface as a solid layer.

Alternatively, the mass transfer medium 500 may be a non-porous, solid catalyst or absorbent material.

The mass transfer medium may be in different forms as illustrated in FIG's 4, 5a and 5b, and 5c, 5d, 5e. FIG. 4 shows the mass transfer medium as a solid material 400 bonded to an outer thin sheet 118. Alternatively, the catalyst material 400 may be bonded to an end block 120.

Another form of mass transfer medium is shown in FIG's 5a and 5b wherein the mass transfer medium 500 is integral to the outer thin sheet 118 as a mass transfer sheet. In this form, the mass transfer medium 500 extends through the thickness of the outer thin sheet and deployed as sandwiched between a pair of inner thin sheets 116 and closed with a pair of end blocks 120. In FIG's 5a and 5b, the mass transfer medium 500 is a porous material having pores 502 or holes either straight through the thickness or not straight as interconnected porosity.

- 11 -

Yet another form of mass transfer medium is shown in FIG's 5c, 5d and 5e. Outer thin sheet 504 has ribs 506 defining slots 508 as a perforated material. In FIG. 5d, outer thin sheet 510 has ribs 512 defining slots 514 that are offset compared to those of outer thin sheet 504. Upon alternate stacking of these outer thin sheets 504, 510 with inner thin sheets 116 therebetween, the cross section shown in FIG. 5e is obtained which is useful for mixing two streams.

Chemical Separations and Conversions

Chemical separations as used herein includes any exchange of a compound or element from one solvent to another where the solvents may be liquid or gas or both. An example is an absorption cycle refrigeration system. In chemical separations, a mass transfer medium 500 in the form of a porous membrane is selected so that a first solvent containing the element or compound does not wet the porous membrane but a second solvent wets the porous membrane and the element or compound in the first solvent transfers to the second solvent and through the porous membrane.

By making the depths of the solvents small, i.e. less than about 1 micron, higher absorption rates are achieved than with larger depths. A microporous contactor unit may be a microporous contactor sheet as shown in FIG. 5 placed between cover sheets. Each cover sheet has a microplenum or at least one microcomponent together with an inlet and an outlet permitting fluid flow across the microporous contactor sheet. A microplenum may be formed with an inner thin sheet 116 in combination with an end block 120.

In most practical systems, to achieve high absorption/desorption rates, heat will need to be

- 12 -

transferred either to or from the absorption/desorption fluids. Accordingly, heat transfer may be combined with the microporous contactor unit.

The pores are preferably as small as practical, on
5 the order of a few microns, i.e. less than about 10
microns, and most preferably less than about 3 microns.
The small pore size provides a strong resistance to a
through-sheet velocity or pressure gradient. A cover or
combination of inner thin sheet 116 with end block 120 is
10 placed over the outer thin sheet having the porous
material. A fluid plenum may thereby be formed that is
less than about 10 microns in height from the sheet to
the cover. Mass diffusion then occurs within a stagnant
film and through the microporous contactor sheet.
15 Micro-components, for example microgrooves, may be
manufactured on one or both sides of the microporous
contactor sheet. Additionally, the microporous contactor
sheet may have no microcomponents itself, but the cover
sheet(s) may have microcomponents for directing fluid
20 flow across the microporous contactor sheet. A further
embodiment is simply a fluid microplenum on either side
of the microporous contactor sheet.

The microporous contactor sheet may be made by
micromachining a metal, ceramic or plastic by, for
25 example Lithography, Galvanoformung (electrodeposition),
Abformung (injection molding), laser micromachining,
electrochemical micromachining, or sintering. Advantages
of micromachined contactor sheets include precise control
of the pore size throughout the sheet.

30 In operation, fluids may flow in parallel,
counterflow, or crossflow. The parallel flow results in
lesser mass flux or extraction, but permits lesser
pressure differential or gradient across the microporous
sheet. When gas is one of the fluids and the gas is to be
35 absorbed into a liquid, it is preferred that the gas pass

- 13 -

through the microporous sheet, but not the liquid. Accordingly, it is preferred that the microporous sheet either be coated so that the liquid does not wet the microporous sheet or have pores sufficiently small so
5 that the liquid is supported by its surface tension and does not flow through the pores.

In the case wherein a microporous sheet is not sufficiently self supporting between the covers, the covers may be made with projections or lands for support
10 of the microporous sheet. Alternatively, as previously discussed, the microporous sheet may have grooves or microcomponents. In either case, projections or lands would support the microporous sheet.

A microporous contactor unit is shown in FIG. 6. A
15 microporous contactor sheet 1300 is placed between two covers 1302, 1304 each having an end block 1306 and an inner thin sheet 1308 that create microplena between the microporous contactor sheet 1300 and the end blocks 1306 upon assembly. Note in this embodiment, the inlet and
20 outlet are through the side of the inner thin sheets 1308. When used as an absorber, a gas is introduced into cover 1302 through inlet 1310. A weak solution enters the cover 1304 through inlet 1312 and the strong solution exits through outlet 1314. When used for solvent
25 extraction, the solvent enters the cover 1302 at inlet 1310 and extract exits outlet 1316. Feed enters inlet 1312 and raffinate exits from outlet 1314. For either absorption or solvent extraction, if heat must be removed or added, a microchannel heat exchanger sheet 1318 may be
30 used as shown. When used as a chemical reactor, specifically for partial oxidation of liquid organics, the gas is oxygen that passes through the microporous contactor sheet 1300.

- 14 -

Example 1

An experiment was conducted to demonstrate separation in the form of gas absorption into a liquid. More specifically, ammonia vapor was absorbed into liquid
5 water. A microporous contactor sheet made of sintered stainless steel having a nominal thickness of 4 mm (1/16 inch), average pore size of 2-5 micron and a porosity of from 30% to 50%. Cover sheets provided microplena having a thickness or distance from the microporous contactor
10 sheet to the inside surface of the cover sheet (film thickness) ranging from about 100 to 300 microns. Within the liquid film on the microporous contactor, the ammonia was absorbed into the water. Ammonia flow rate varied from 0-4 g/min with water flow rate ranging from 0-33
15 g/min. Temperature ranged from 20-60_C for isothermal and adiabatic test runs. Absorption pressure was from 15 to 30 psia.

Results are shown in FIG. 7. Considering first the measured data for the adiabatic test, the points 1400
20 represent actual measurements of ammonia concentration at film thicknesses of 100 and 300 microns. The theoretical maximum absorption or "equilibrium" (which is a function of temperature) was calculated and represented by point 1402 for the adiabatic test. As the absorption film
25 thickness is decreased, the measured ammonia concentration approaches the theoretical maximum.

Similar results are shown for the isothermal test represented by actual measurement points 1404 and equilibrium points 1406. Had the test been truly
30 isothermal, the equilibrium line would have been horizontal. The slight slope of that line indicates a difference in temperature at the different film thicknesses.

Comparing the adiabatic data and the isothermal
35 data, it is clear that greater absorption is achievable

- 15 -

with heat removal (isothermal) than with no heat removal (adiabatic).

Porous or Perforated Material Fabrication

5 Stainless steel porous material or membranes were produced using commercial photochemical machining at Microphoto, Inc., Roseville, MI. The porous material was very clean, well defined, had no burrs, and excellent part to part reproducibility. However, this process is
10 limited to producing holes of a diameter no smaller than the thickness of the sheet. We made a perforated sheet with holes of about 100 micrometers in diameter spaced 250 micrometers apart on 50 micrometer thick stock.

 Using a 50 micrometer thick polyimide (Kapton)
15 sheet, holes of 15 micrometer diameter were individually laser drilled in a 15 X 15 square pattern on a 35 micrometer spacing. An overall matrix was 10 mm X 80 mm. The laser micromachining system was a Potomac model LMT-4000 using a 248-nm KrF excimer laser (Potomac model TGX-
20 1000). The laser ran 75 msec per location at 2-KHz pulse rate (0.045 mJ/pulse) and no aperture in the beam. Total machine time to produce the matrix was nearly 45 hours.

 A polymer porous material was also made using a mask patterning process. A commercial excimer laser
25 machine (Resonetics, Inc., Nashua, NH) had a rectangular beam profile (about 8 mm X about 25 mm) permitting multiple holes at a time to be made through a mask, significantly reducing overall machining time. Holes of 31 micrometer diameter spaced 61.5 micrometer in a 10 mm
30 X 80 mm matrix were made in about 20 minutes. The KrF excimer laser (248 nm) had a pulse energy of 257 mJ and pulse rate of 100 Hz was used.

 In assemblies using polymer porous materials, it is possible to use metal inner thin sheets and outer thin
35 sheets, but bonding would be by clamping or bolting,

- 16 -

relying on the polymer margin for sealing.
Alternatively, the inner thin sheets and outer thin
sheets may be a polymer as well wherein the entire
assembly could be heat or chemically bonded.

5

CLOSURE

While a preferred embodiment of the present
invention has been shown and described, it will be
10 apparent to those skilled in the art that many changes
and modifications may be made without departing from the
invention in its broader aspects. The appended claims
are therefore intended to cover all such changes and
modifications as fall within the true spirit and scope of
15 the invention.

- 17 -

CLAIMS

We claim:

- 5 1. A method of making a microchannel mass exchanger, comprising the steps of:
- (a) forming at least one inner thin sheet having a solid margin around a circumference, said solid margin defining a slot through a thickness;
- 10 (b) forming at least one outer thin sheet having at least two header holes positioned within said solid margin and positioned at opposite ends of a slot length, wherein said at least one inner thin sheet is placed adjacent said at least one outer thin sheet, said
- 15 solid margin sealably spacing said at least one outer thin sheet said at least one outer thin sheets defining at least one longitudinal wall of a flow channel having a length parallel to a thin sheet length, wherein a fluid enters through one of said header holes into said slot to
- 20 flow in a direction parallel or longitudinal to the length of said flow channel and exits through another of said header holes;
- (c) placing a mass transfer medium on at least one of said at least one outer thin sheet within
- 25 the solid margin;
- (d) stacking said at least one inner thin sheet in contact with said at least one outer thin sheets into a stack and placing an end block on said at least one inner thin sheet as a pre-bonded assembly; and
- 30 (e) bonding the pre-bonded assembly into said microchannel mass exchanger.

2. The method as recited in claim 1, wherein said mass transfer medium is a catalyst material bonded to the

- 18 -

at least one outer thin sheet or to the at least one end block.

3. The method as recited in claim 1, wherein said
5 mass transfer medium is integral to the at least one
outer thin sheet as a mass transfer sheet, said mass
transfer medium extending through the thickness of said
at least one outer thin sheet, wherein said mass transfer
sheet is sandwiched between a pair of inner thin sheets
10 and closed with a pair of end blocks.

4. The method as recited in claim 3, wherein said
mass transfer medium is a porous material.

15 5. The method as recited in claim 3, wherein said
mass transfer medium is a perforated material.

6. The method as recited in claim 3, wherein said
mass transfer medium is a solid material.

20 7. The method as recited in claim 6, wherein said
solid material is selected from the group consisting of
catalyst, hydrophobic material, hydrophylic material,
self assembling monolayer, and combinations thereof.

25 8. The method as recited in claim 1, wherein an
aspect ratio of a width of the slot to the thickness of
the slot is at least 10.

30 9. The method as recited in claim 4, wherein at
least two of said at least one inner thin sheet each has
two header holes and are sandwiched between at least
three of said at least one outer thin sheet and stacked
to permit passage of at least two fluids on opposite
35 sides of said mass transfer medium.

- 19 -

10. The method as recited in claim 9, wherein one of said fluids is a gas and another of said fluids is a liquid.

5 11. A microchannel mass exchanger, comprising:

(a) at least one inner thin sheet having a solid margin around a circumference, said solid margin defining a slot through a thickness;

10 (b) at least one outer thin sheet having at least two header holes positioned within said solid margin and positioned at opposite ends of a slot length, wherein said at least one inner thin sheet is placed adjacent said at least one outer thin sheet, said solid margin sealably spacing said at least one outer thin
15 sheet said at least one outer thin sheets defining at least one longitudinal wall of a flow channel having a length parallel to a thin sheet length, wherein a fluid enters through one of said header holes into said slot to flow in a direction parallel or longitudinal to the
20 length of said flow channel and exits through another of said header holes;

(c) a mass transfer medium on at least one of said at least one outer thin sheet within the solid margin;

25 (d) said at least one inner thin sheet in contact with said at least one outer thin sheets into a stack with an end block on said at least one inner thin sheet as a pre-bonded assembly; and

30 (e) the pre-bonded assembly bonded into said microchannel mass exchanger.

12. The apparatus as recited in claim 11, wherein said mass transfer medium is a catalyst material bonded to the at least one outer thin sheet.

35

- 20 -

13. The apparatus as recited in claim 11, wherein
said mass transfer medium is integral to the at least one
outer thin sheet as a mass transfer sheet, said mass
transfer medium extending through the thickness of said
5 at least one outer thin sheet, wherein said mass transfer
sheet is sandwiched between a pair of inner thin sheets
and closed with a pair of end blocks.

14. The apparatus as recited in claim 13, wherein
10 said mass transfer medium is a porous material.

15. The apparatus as recited in claim 13, wherein
said mass transfer medium is a perforated material.

15 16. The apparatus as recited in claim 13, wherein
said mass transfer medium is a solid material.

17. The apparatus as recited in claim 16, wherein
said solid material is selected from the group consisting
20 of catalyst, hydrophobic material, hydrophylic material,
self assembling monolayer, and combinations thereof.

18. The apparatus as recited in claim 11, wherein
an aspect ratio of a width of the slot to the thickness
25 of the slot is at least 10.

19. The apparatus as recited in claim 14, wherein
at least two of said at least one inner thin sheet each
has two header holes and are sandwiched between at least
30 three of said at least one outer thin sheet and stacked
to permit passage of at least two fluids on opposite
sides of said mass transfer medium.

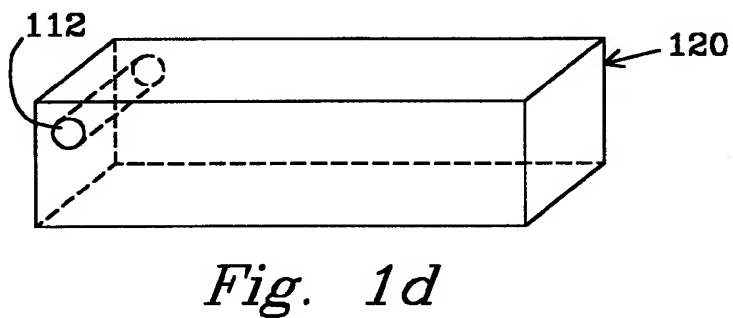
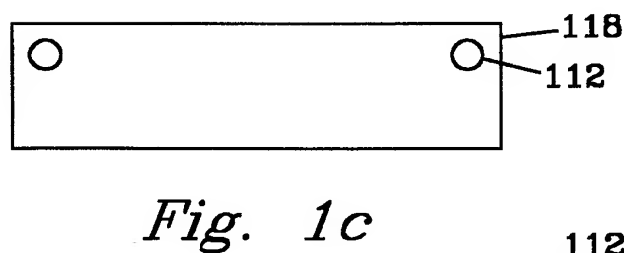
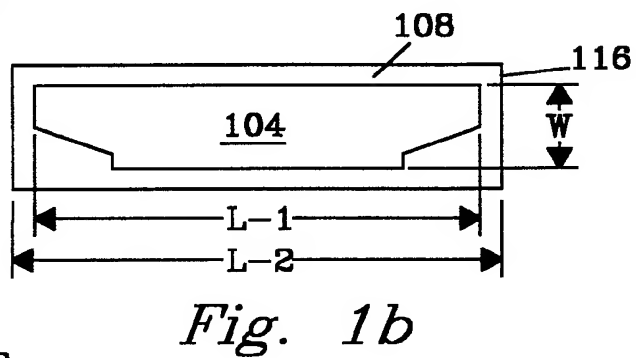
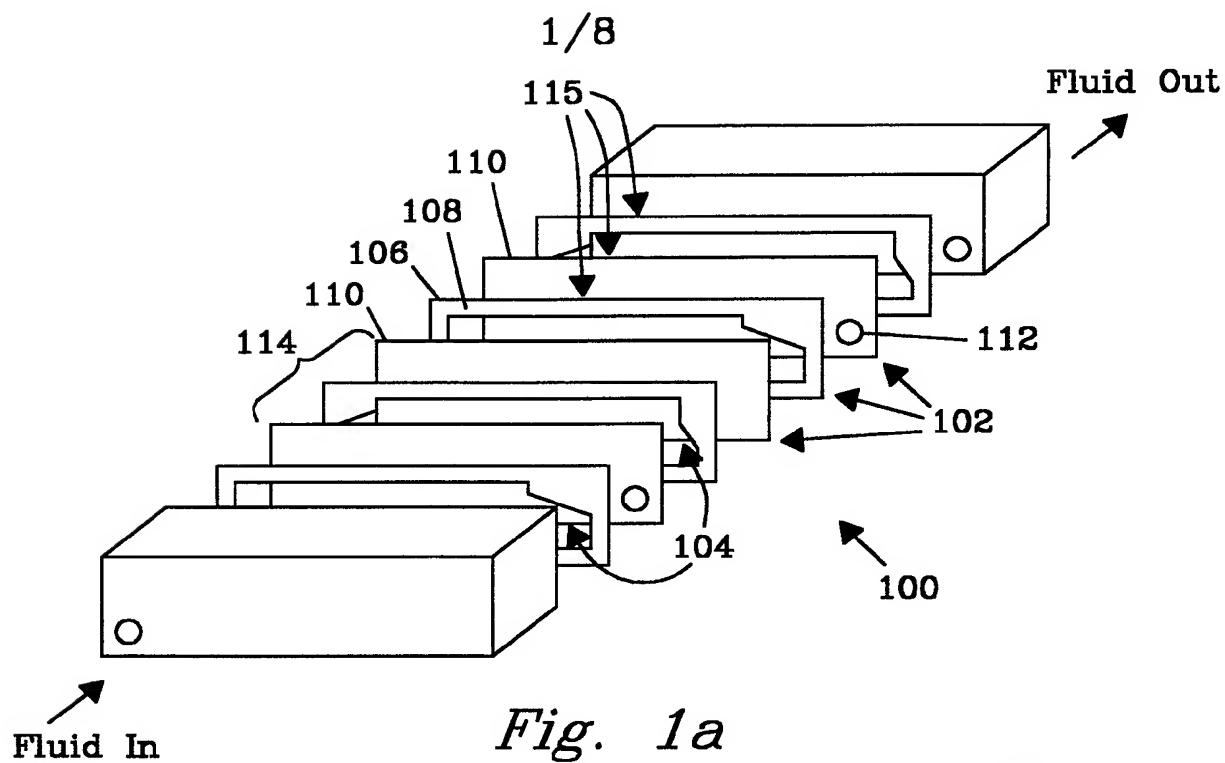
- 21 -

20. The apparatus as recited in claim 19, wherein one of said fluids is a gas and another of said fluids is a liquid.

5 21. The apparatus as recited in claim 11, wherein said microchannel mass exchanger has an outer surface defined by a plurality of edge thicknesses of said stacked plurality of inner and outer thin sheets, said
10 outer surface proximate a thermal load so that said thermal load is transmitted via conduction through said plurality of stacked thin sheets and also transmitted via convection between said stacked plurality of thin sheets and said fluid.

15 22. The apparatus as recited in claim 11, wherein said microchannel mass exchanger is a microchannel adsorber.

20 23. The apparatus as recited in claim 11, wherein said microchannel mass exchanger is a microchannel desorber.



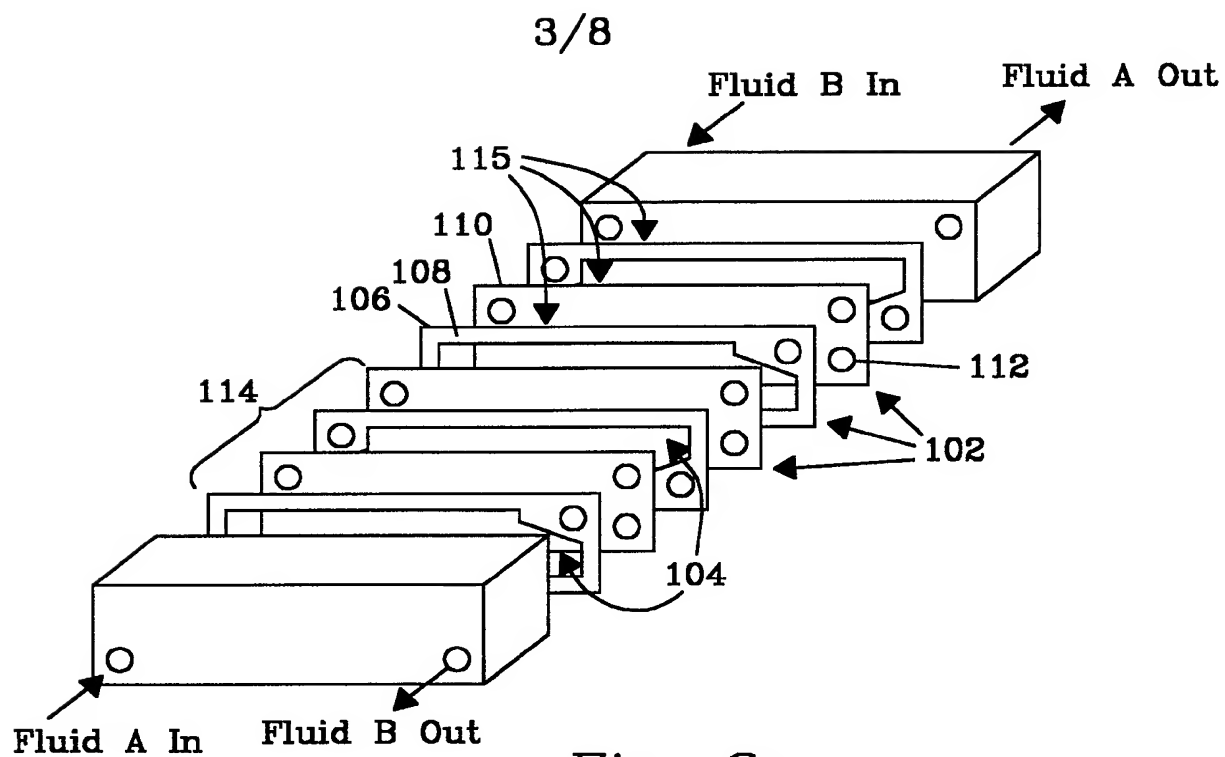


Fig. 3a

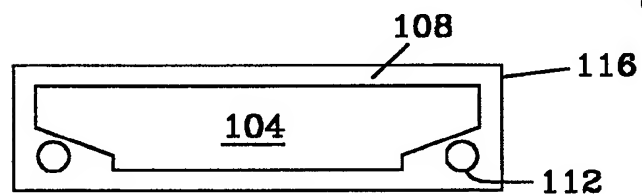


Fig. 3b



Fig. 3c

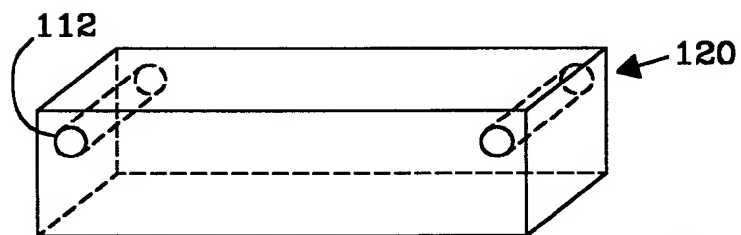


Fig. 3d

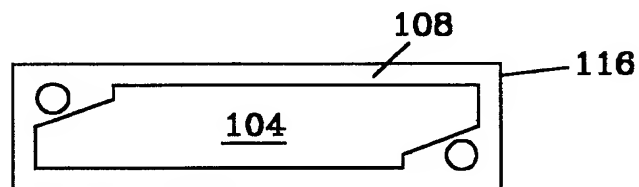


Fig. 3e

4/8

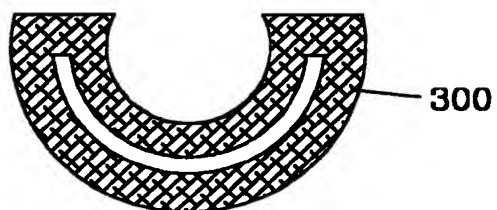


Fig. 3f

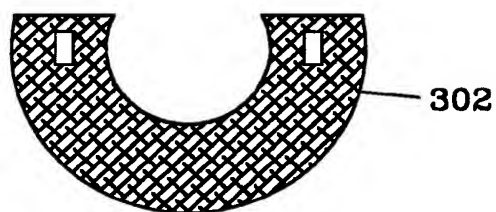


Fig. 3g

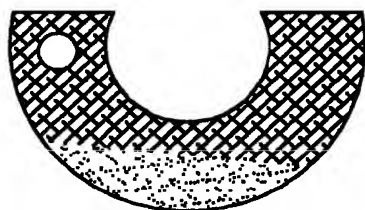


Fig. 3h

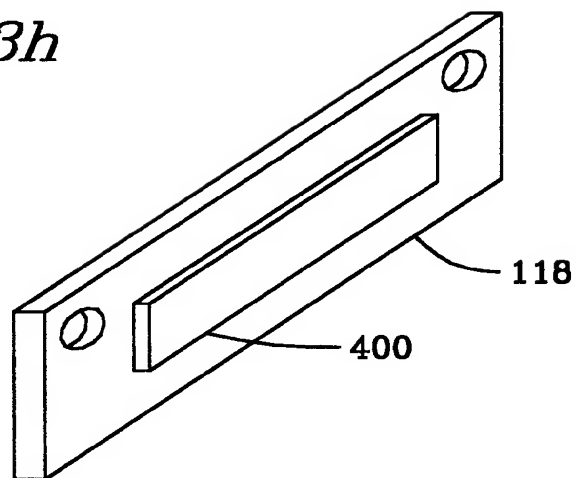
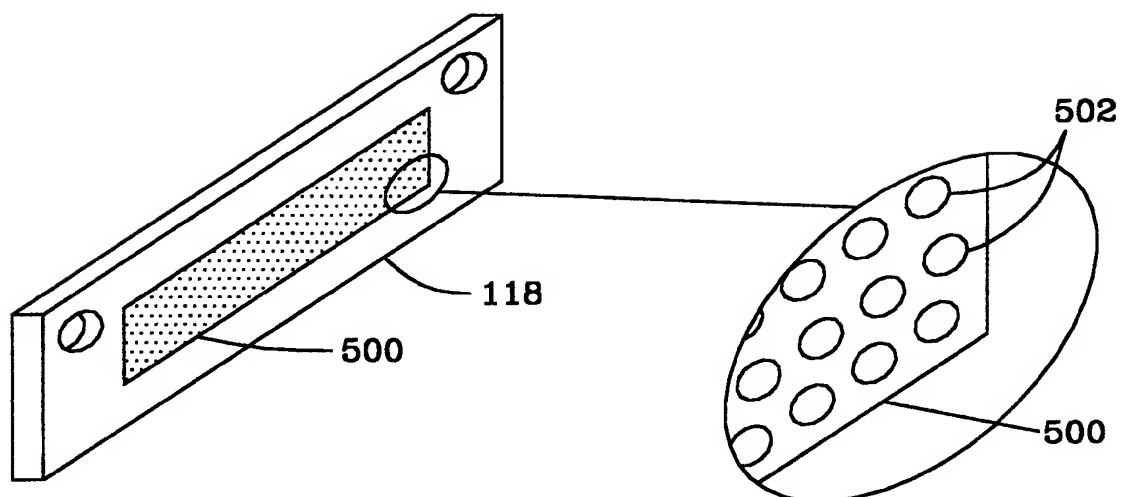
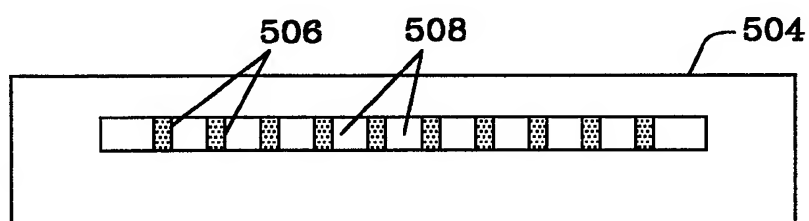
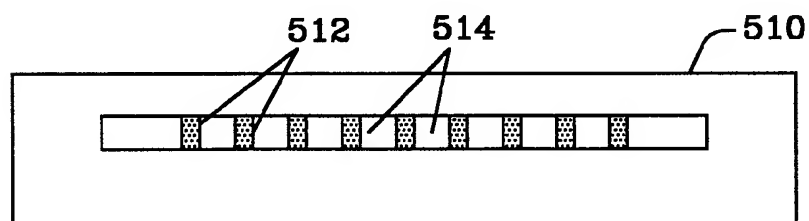
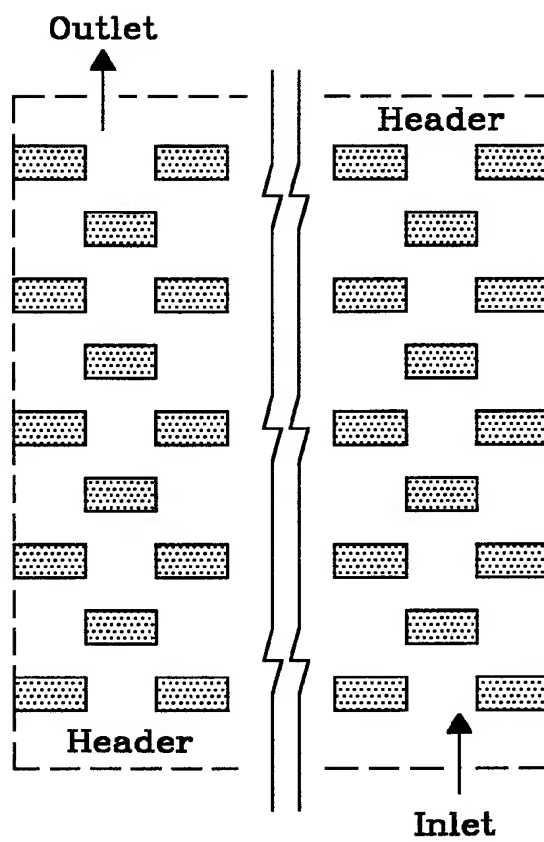


Fig. 4

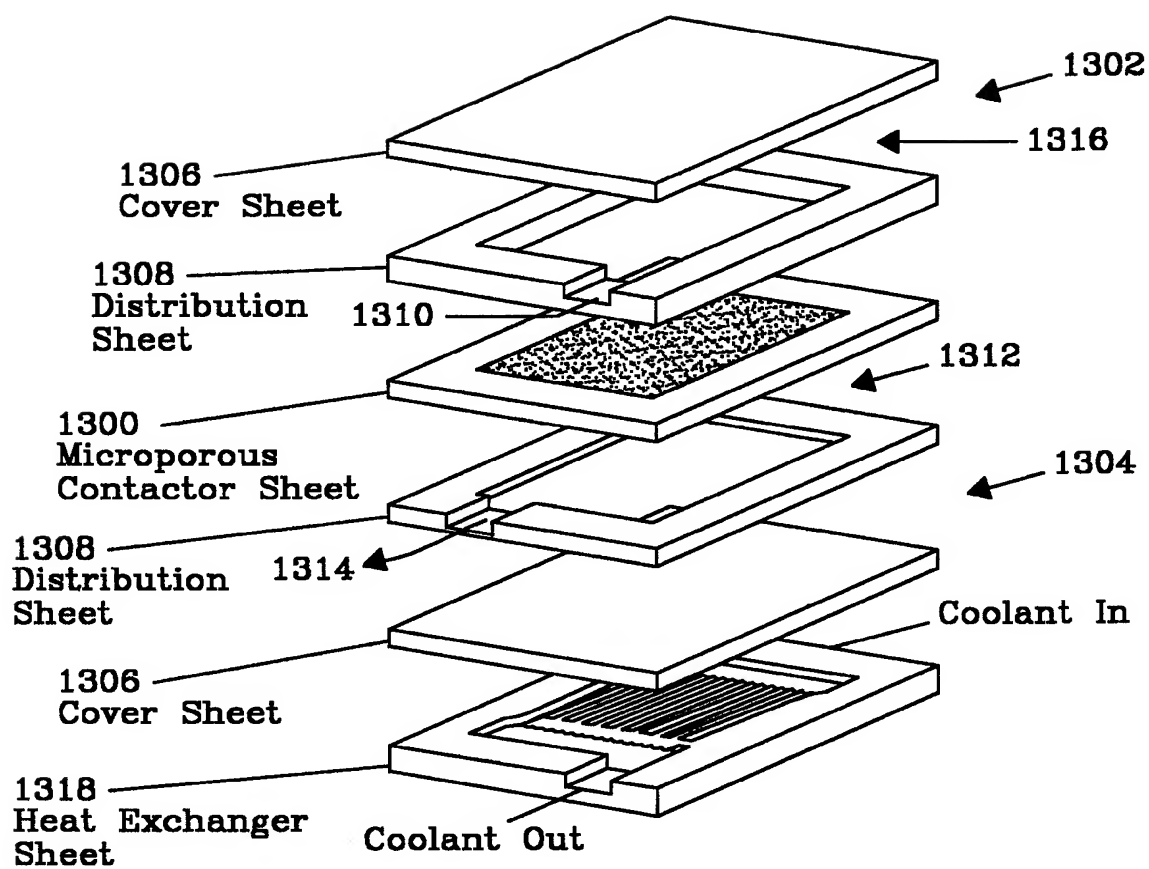
5/8

*Fig. 5a**Fig. 5b**Fig. 5c**Fig. 5d*

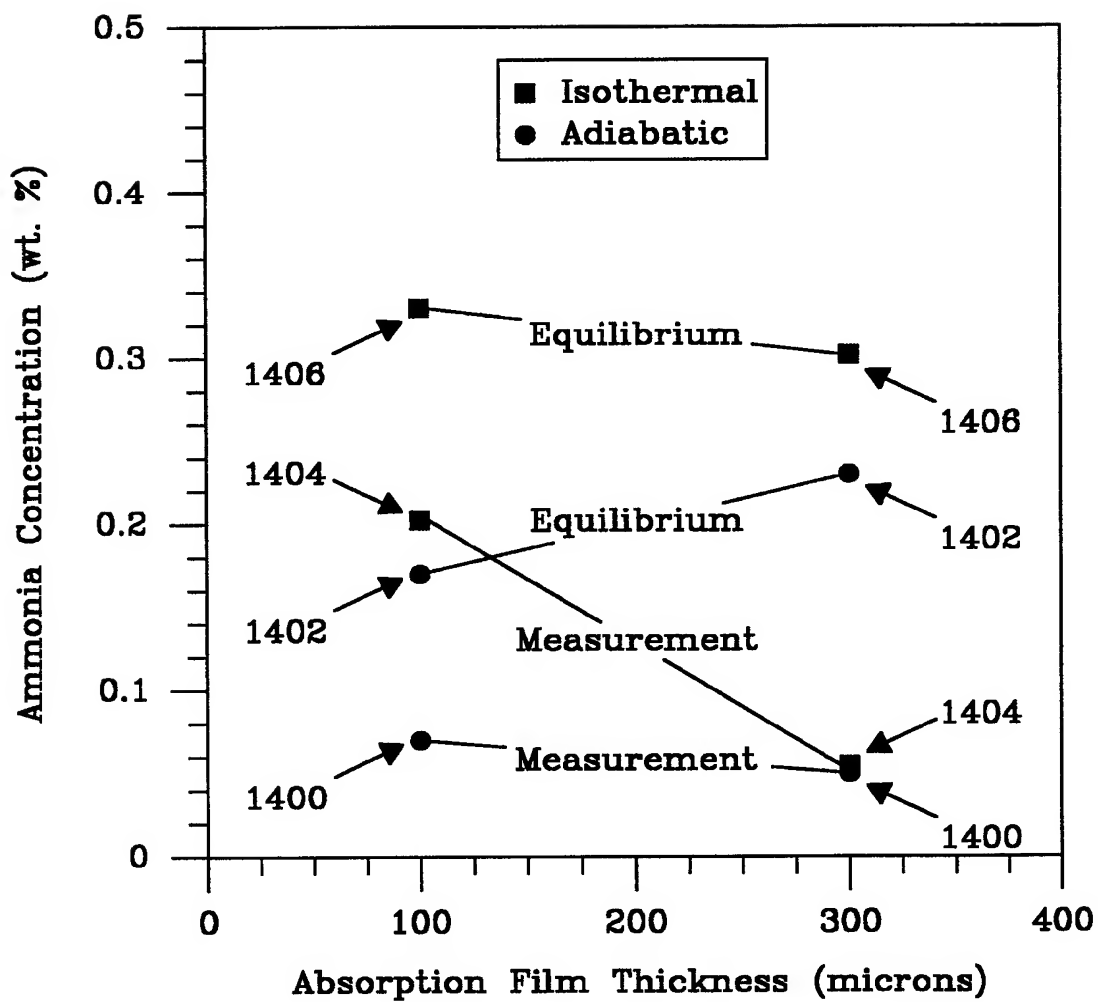
6/8

*Fig. 5e*

7/8

*Fig. 6*

8/8

*Fig. 7*

INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 98/19567

A. CLASSIFICATION OF SUBJECT MATTER

IPC 6 B01J19/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 B01J B01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 484 278 A (CIBA-GEIGY AG) 6 May 1992 see the whole document ----	1-23
A	EP 0 754 492 A (BASF CORPORATION) 22 January 1997 see the whole document ----	1-23
A	DE 195 11 603 A (NORBERT SCHWESINGER & THOMAS FRANK) 2 October 1996 see the whole document ----	1-23
A	WO 97 14497 A (BATTELLE MEMORIAL INSTITUTE) 24 April 1997 see the whole document ----	1-23
A	US 3 856 270 A (HERMAN W. HEMKER) 24 December 1974 see the whole document -----	1



Further documents are listed in the continuation of box C.



Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search

13 January 1999

Date of mailing of the international search report

25/01/1999

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

Stevnsborg, N

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/US 98/19567

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
EP 484278	A	06-05-1992	DE 59105165 D JP 4307349 A US 5250263 A	18-05-1995 29-10-1992 05-10-1993
EP 754492	A	22-01-1997	US 5658537 A CA 2176432 A US 5843385 A	19-08-1997 19-01-1997 01-12-1998
DE 19511603	A	02-10-1996	WO 9630113 A EP 0879083 A	03-10-1996 25-11-1998
WO 9714497	A	24-04-1997	US 5811062 A AU 1073497 A EP 0862493 A	22-09-1998 07-05-1997 09-09-1998
US 3856270	A	24-12-1974	NONE	